Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Small Antenna Designs for LTE Mobile Devices

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Abstract: Long-term evolution (LTE) is one of the 4th generation (4G) mobile communication technologies that are developed at different frequencies, ranging from 400 MHz to 4 GHz with bandwidths up to 20 MHz. LTE standard allows multiple antennas on both ends of the wireless channel i.e. multiple-input-multiple-output (MIMO) technology to support high data rate 4G applications. Integrating multiple antenna elements is a key LTE standard, which currently supports a maximum of four antenna elements on mobile devices. MIMO technology exploits multiple antennas to increase channel capacity in both direct line-of-sight and multi-path scenarios. Although increasing the number of antenna elements theoretically increases channel capacity, research has shown that MIMO technology achieves optimal performance when multiple antenna elements operate as a reconfigurable two-element system due to strong mutual coupling (P. Manos, and V. C. Karaboikis, IEEE Trans. Antennas Propag., 56, 2067 – 2078, 2008).

However, modern day handsets are experiencing miniaturization where thin and slim shapes are making it difficult to integrate several antennas onto a small, thin PCB. Keeping the modern day miniaturization concept in mind, this paper presents a compact antenna designs that minimize the space requirements and still be able to achieve low correlation for hand held mobile devices (smart phones and tablets). Antenna designs emerge from the concept of combining the orthogonally oriented antennas that can be excited separately as well as together. The antenna designs are optimized for high port-to-port isolation for efficient MIMO performance. Also paper will present a multiport matching network design to optimize the total radiation efficiency, while minimizing mutual coupling.

Simulation results (FEKO Suite 7.0, Altair Engineering, 2015) will also be presented for the performance of the antenna system in the presence of the human body (head, hands etc.) along with determination of Specific Absorption Rate (SAR) calculations.

Dr. C. J. Reddy received his Ph.D. in 1988 in Electrical Engineering from the Indian Institute of Technology, Kharagpur, India. Dr. Reddy was a research associate at NASA Langley Research Center, and previously a research fellow at the Natural Sciences and Engineering Research Council (NSERC) of Canada. While conducting research at NASA Langley, he developed various computational codes for electromagnetics and received a Certificate of Recognition from NASA for development of a hybrid Finite Element Method/Method of Moments/Geometrical Theory of Diffraction code for cavity backed aperture antenna analysis. Currently, Dr. Reddy is the Vice President, Business Development-Electromagnetics at Altair Engineering, Inc.(www.altair.com). At Altair, he is leading the marketing and support of commercial 3D electromagnetic software, FEKO in Americas. Dr. Reddy is also the President of Applied EM Inc (www.appliedem.com), a small company specializing in computational electromagnetics, antenna design and development. At Applied EM, Dr. Reddy successfully led many Small Business Innovative Research (SBIR) projects from the US Department of Defense (DoD). Dr. Reddy is a Senior Member of Institute of Electrical and Electronics Engineers (IEEE) and also a Senior Member of Antenna Measurement Techniques Association (AMTA). He has been elected Fellow of the Applied Computational Electromagnetic Society (ACES) in 2012 and served on ACES Board of Directors from 2006 to 2012. Currently he serves as the Secretary of ACES. Dr. Reddy is a member of IEEE APS - Industry Initiatives Committee (IIC). He published 35 journal papers, 54 conference papers and 17 NASA Technical Reports to date. Dr. Reddy is a co-author of the book, "Antenna Analysis and Design Using FEKO Electromagnetic Simulation Software," published in June 2014 by SciTech Publishing (An Imprint of IET). Dr. Reddy was the General Chair of ACES 2011 Conference held in Williamsburg, VA during March 27-31, 2011. And also ACES 2013 conference, Monterey CA (March 24-28, 2013). He was the Co-General Chair of 2014 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting held during July 6-11, 2014 in Memphis, TN. Dr. Reddy is the General Co-Chair for ACES 2015 conference held in Williamsburg, Virginia during March 22-26, 2015.

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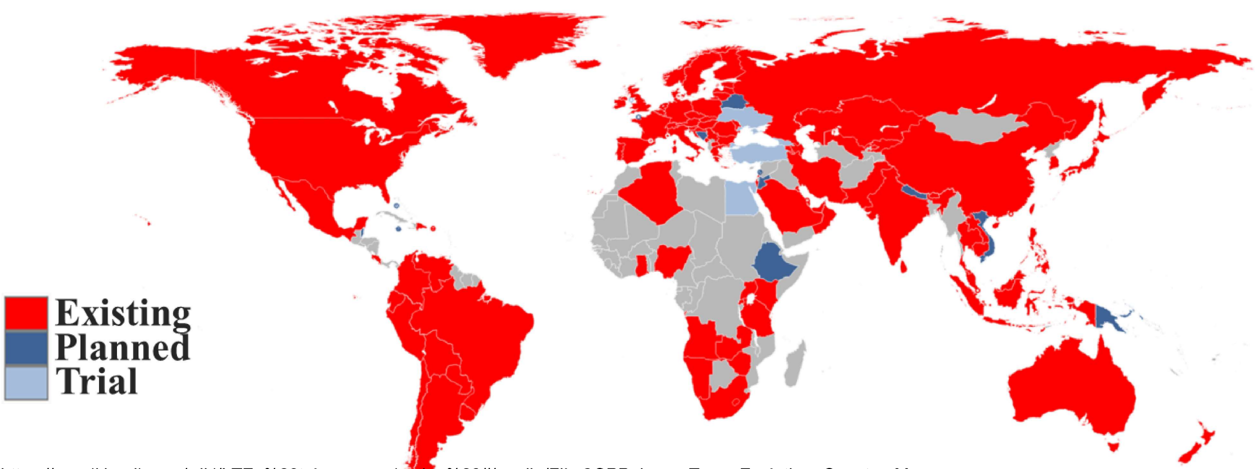
Outline

- Motivation
- LTE-MIMO
- Design Challenges
- Antenna Designs for Smart Phones
- Antenna Designs for Tablets
- Conclusions

Motivation

- **LTE Experiencing Increased Popularity**
  - — Tablets are >**50%** of the Personal Computer Market
  - — 3 in 5 smartphones shipped in 2015 were LTE capable
  - — 900 million LTE smartphones were shipped globally in 2015
  - — **LTE Coverage Increasing**



https://en.wikipedia.org/wiki/LTE_%28telecommunication%29#/media/File:3GPP_Long_Term_Evolution_Country_Map.svg

List of countries by 4G LTE penetration
OpenSignal.com - June 2015

Rank	Country/Territory	Penetration
1	South Korea	97%
2	Japan	90%
3	Hong Kong	86%
4	Kuwait	86%
5	Singapore	84%
6	Uruguay	84%
7	Kazakhstan	81%
8	Netherlands	80%
9	Bahrain	79%
10	United States	78%
11	Sweden	78%
12	China	76%
13	Qatar	75%
14	Australia	74%
15	Estonia	74%

LTE - MIMO

- **Multiple Input Multiple Output (MIMO)**
  - Up to 4 x 4 Configuration
- **Frequency Bands**
  - Flexibility Speeds up Deployment
  - 700, 900, 1800, and 2600 MHz
- **Closed-Loop Scheme**
  - Awareness Facilitates Optimal Operation

Technology	Advantages
Transmit Diversity	Throughput (Reliability)
Spatial Multiplexing	# Streams (Data Rate)
Beamforming	Suppress Interference

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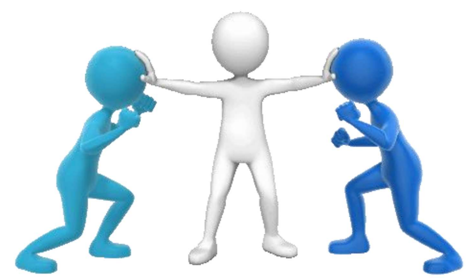
Design Challenges

- **No LTE Design Restrictions on Mobile Devices**
- **General Wireless Communication Challenges**
  - Mitigate Multi-Path Fading
  - Maximize Capacity
  - Minimize Specific Absorption Rate
- **Size Preferences Impose Design Challenges**
  - Matching
  - Isolation
  - In-Situ Performance



Antenna Design for Smart Phones

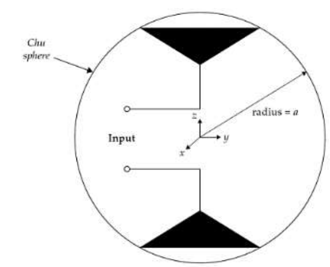
- An ESA is an antenna that satisfies the condition

ka < 0.5

'*k*' is the wave number $2\pi/\lambda$

'*a*' is the radius of the minimum size sphere that encloses the antenna

Chu sphere **is the minimum circumscribing sphere enclosing the antenna of maximum dimension 2a**



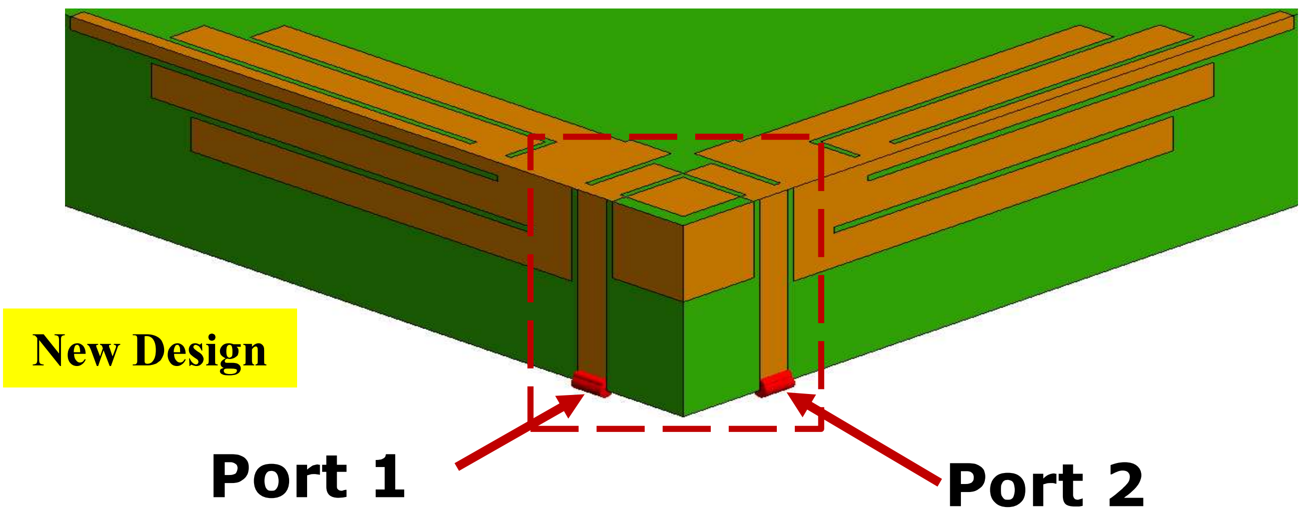
Thickness ~ 1cm
Length ~ 6cm

Frequency = 2.6GHz
Wavelength = 11.5cm

ka ~ 0.5, length (2a) ~ 2cm

Dual Port ESA

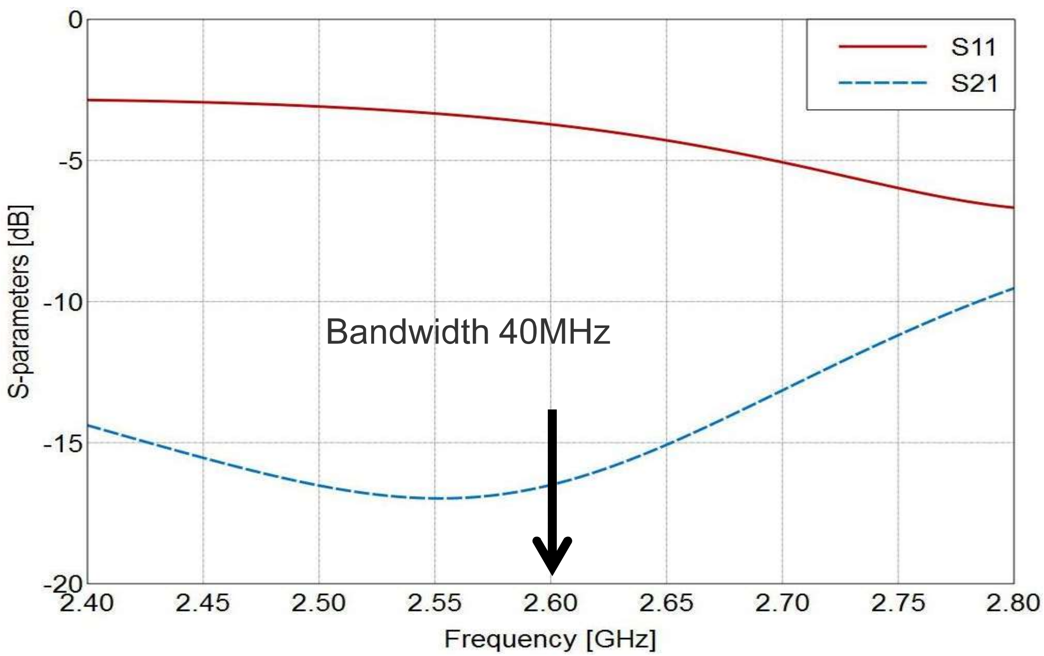
- To go with present day typical handset (115x60x10 mm), we designed a dual-port ESA
- The symmetry in the novel design keeps the antenna characteristics identical for both radiating elements

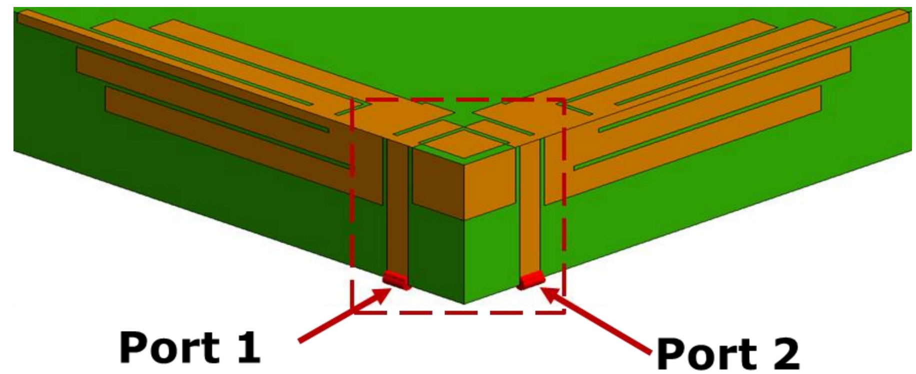


Substrate (FR4)

Thickness	*= 5 mm*
Dielectric constant	*= 4.8*
Loss tangent	*= 0.017*

Port to Port Isolation – Initial Design

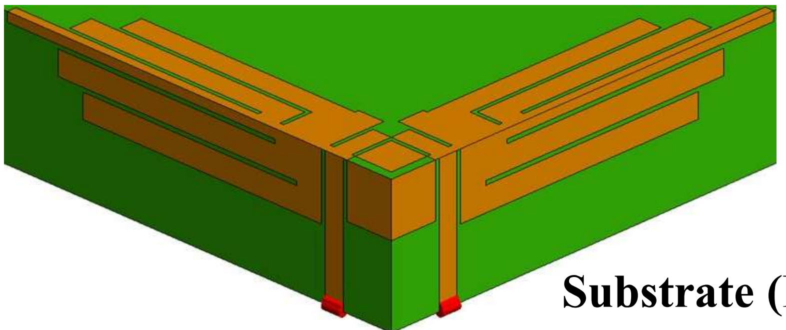




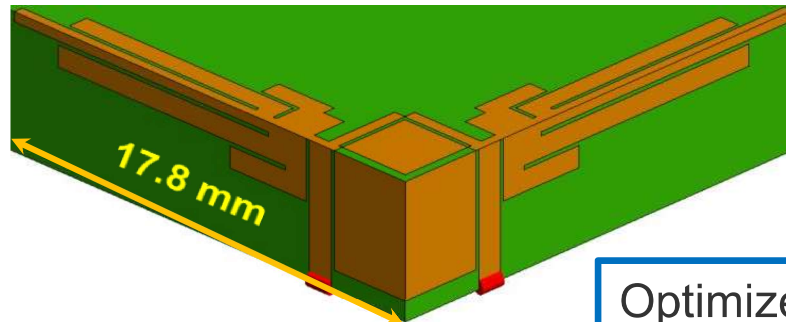
- Good Isolation
- Poor Input Matching

Port to Port Isolation – Optimized Design

Initial Design



Optimized Design



Optimized with Hybrid PSO + Simplex

Substrate (FR4)

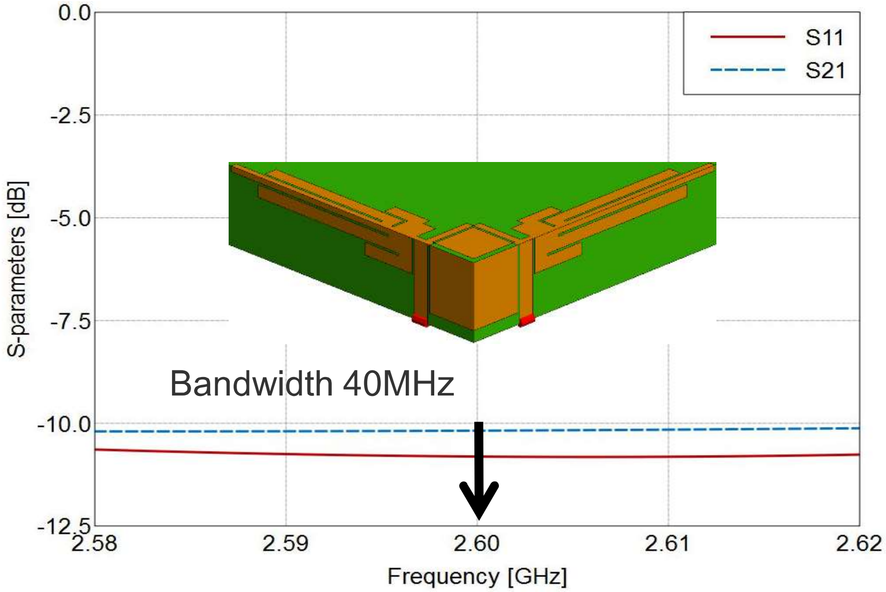
Thickness	***= 5 mm***
Dielectric constant	***= 4.8***
Loss tangent	***= 0.017***

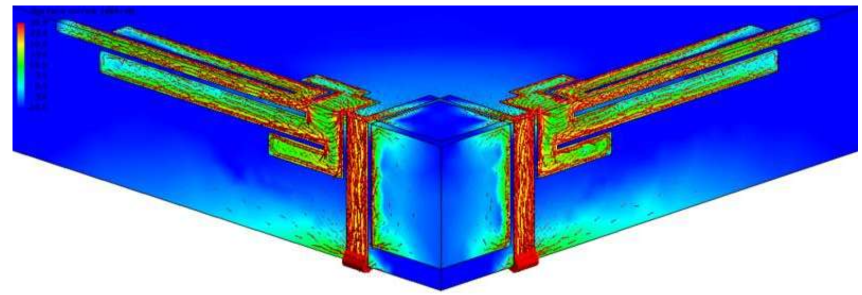
Max. length of the radiating element, 2a = 17.8 mm

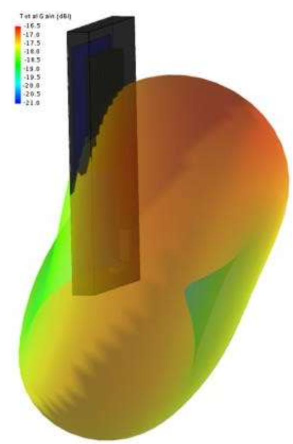
Wave number, k = 2π/λ = 0.0545

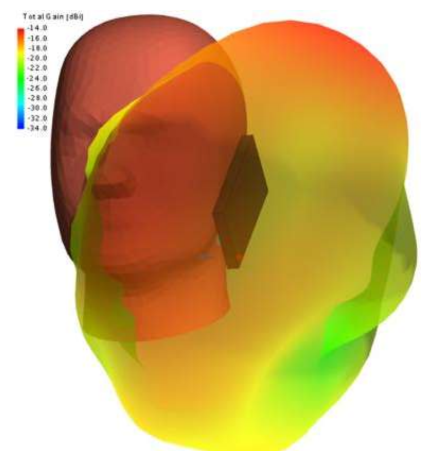
ESA condition, ka = 0.0545*17.8/2 = 0.485 < 0.5

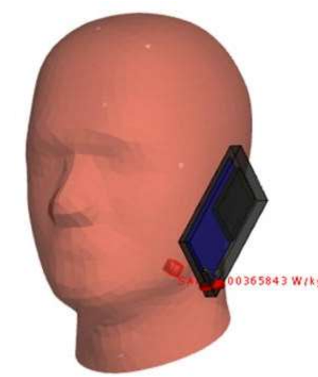
Optimized Performance







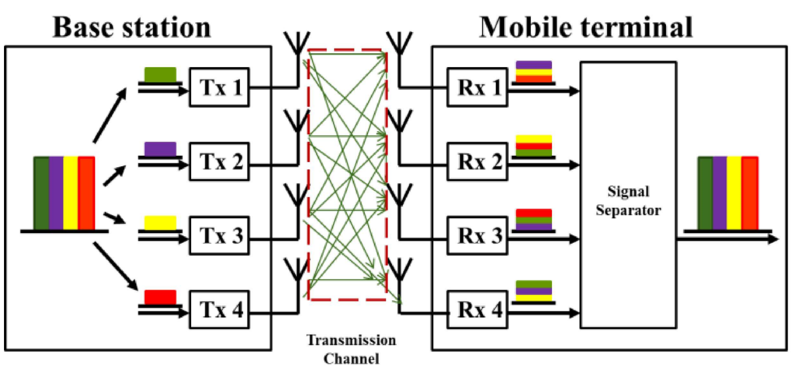




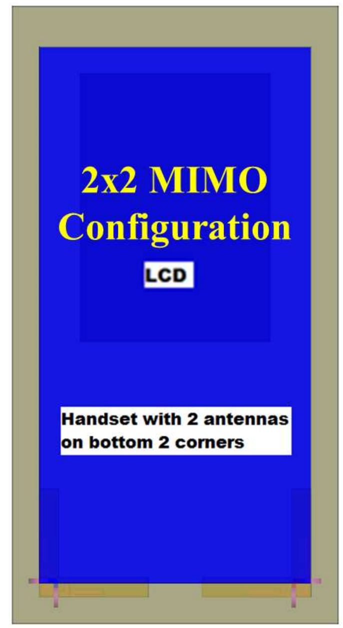
The volume averages SAR of 1 g cube (US standard)

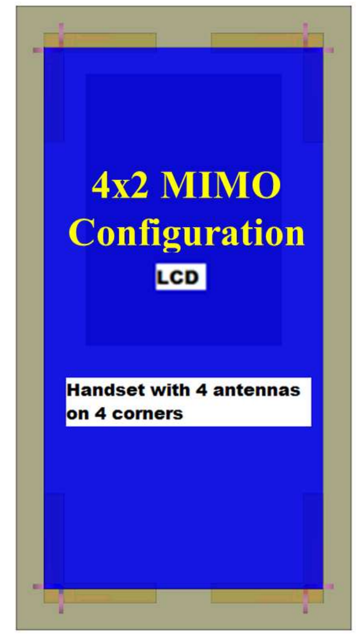
Multiple Input – Multiple Output (MIMO)

- **LTE standard allows multiple antennas on both ends of the wireless channel to support high data rate applications**
- **MIMO technologies have been widely used in LTE to improve downlink peak rate, cell coverage, as well as average cell throughput**



MIMO Configurations





Correlation Matrix

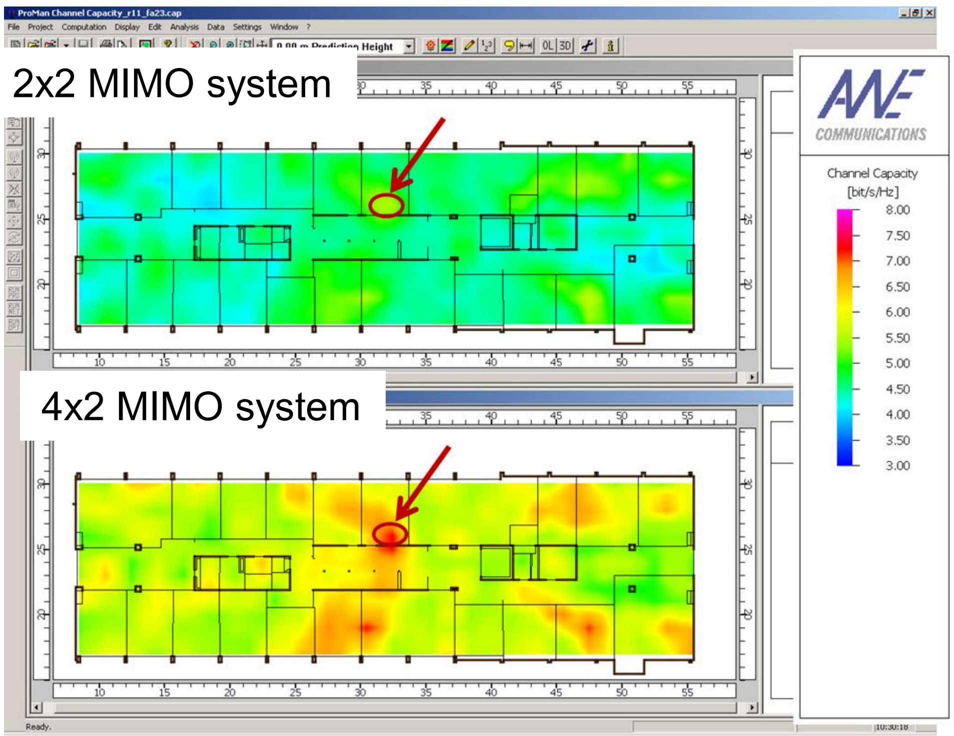
$$H(t) = \begin{pmatrix} h_{1,1}(t) & \dots & h_{1,N_T}(t) \\ \dots & \dots & \dots \\ h_{N_R,1}(t) & \dots & h_{N_R,N_T}(t) \end{pmatrix}$$

Channel Capacity

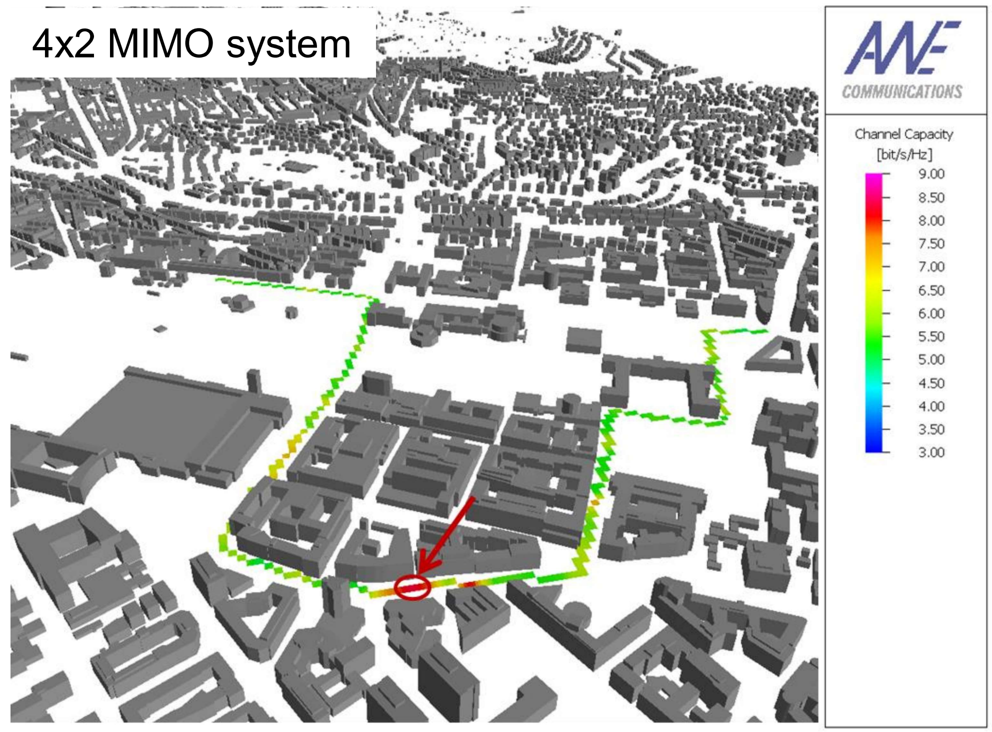
$$C = \frac{1}{N_F} \sum_{l=0}^{N_F-1} \log_2\left(\det\left[I_{N_R} + \frac{\rho}{N_T} \cdot H_F(l) \cdot H_F(l)^H \right] \right) \text{ [bit/s/Hz]}$$

Channel Capacity

Indoor Environment

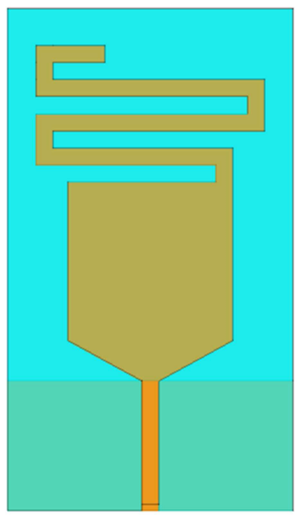


Urban Environment



Antenna Design for Tablets

- **Ultra-Wideband Planar Monopole**
  - 1700 – 2900 MHz
- **Meandering Microstrip Line is Loaded**
  - Provides Resonance at LTE 700 MHz Band
- **5 Frequency Bands**
  - 746 – 787 MHz
  - 1710 – 1755 MHz
  - 2110 – 2155 MHz
  - 2305 – 2400 MHz
  - 2500 – 2690 MHz
- **Size**
  - 88 x 50 x 1.6 mm



Yuan Yao, etc., "Multiband Planar Monopole Antenna for LTE MIMO Systems", ***International Journal of Antennas and Propagation, Vol. 2012, Article ID 890705.***

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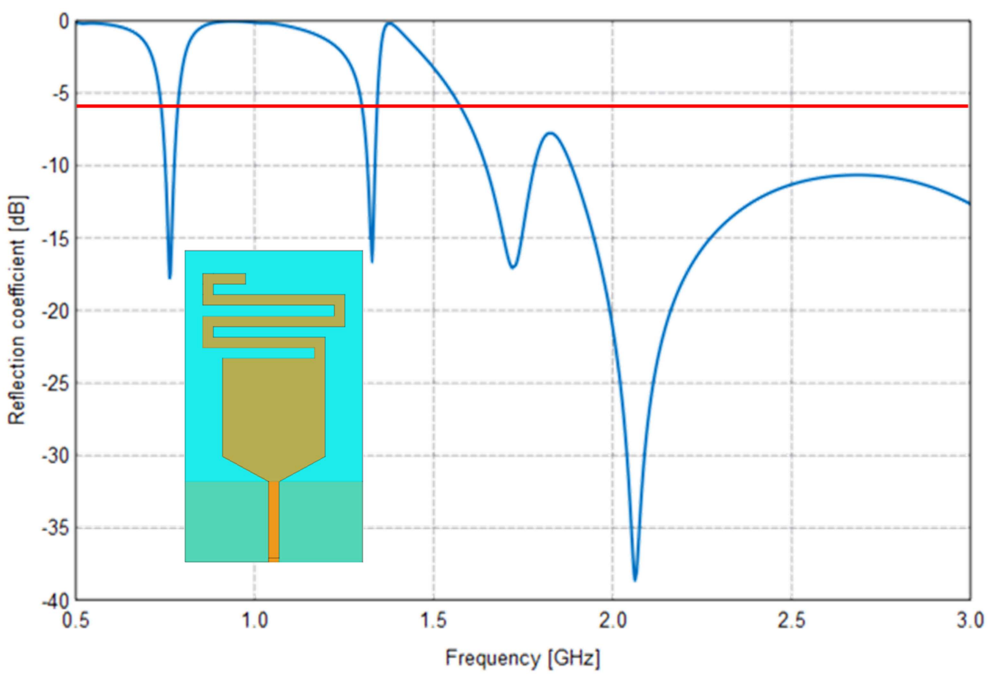
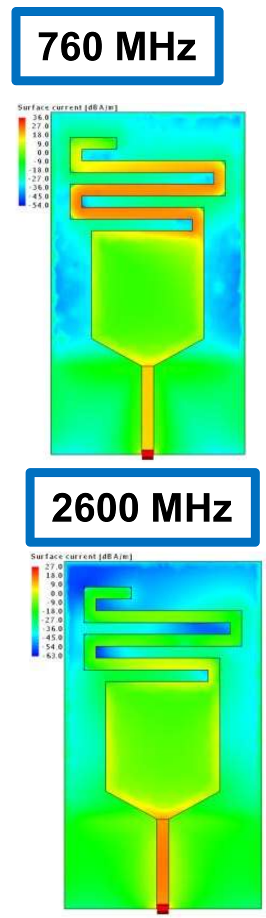
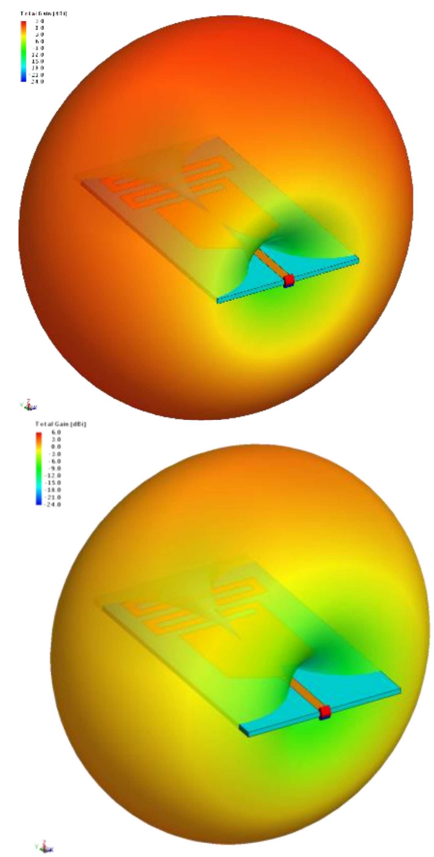
Multi-band LTE Antenna





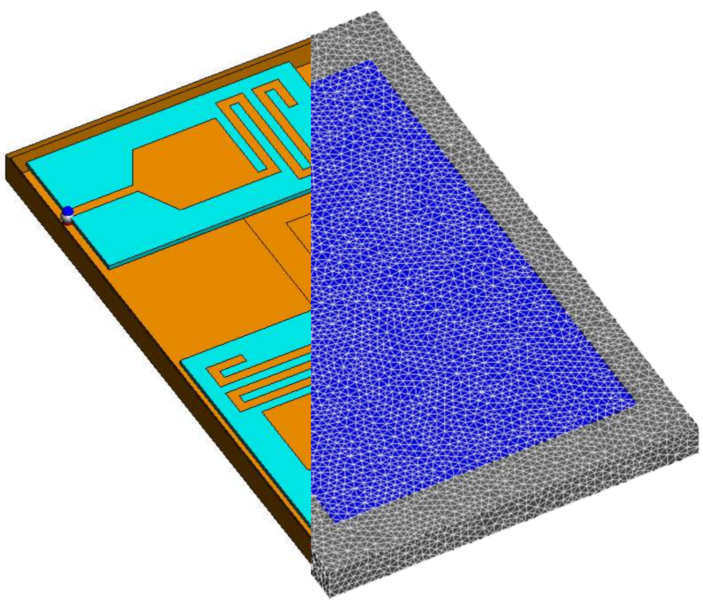


Excellent Matching Across LTE Bands

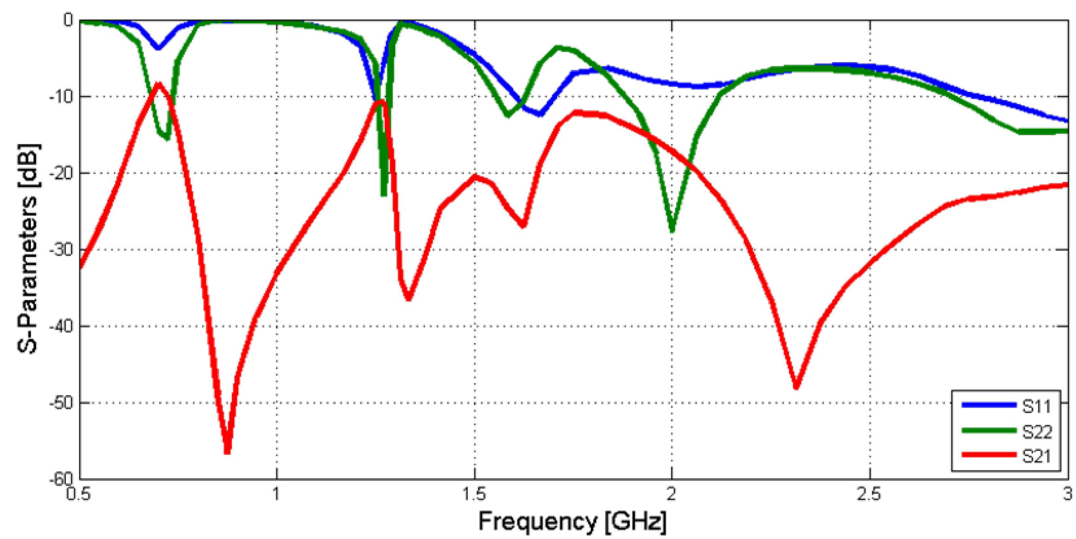
Reflection Coefficient < -6 dB

Integration with Tablet

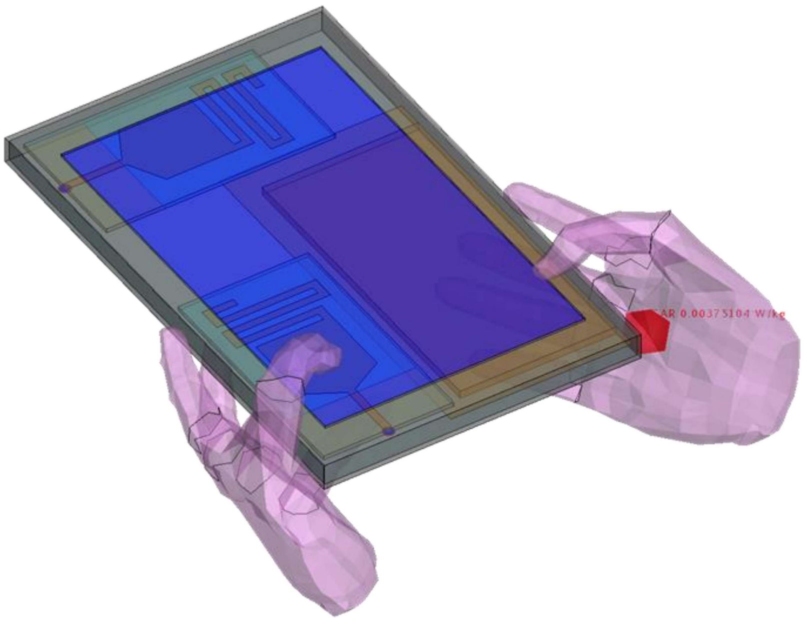
Model Includes
2 Antennas, LCD Display, Case, Battery and PCB



	Height	Width	Depth
Model	193 mm	121.9 mm	9.9 mm
iPad Mini	200 mm	134.7 mm	7.2 mm



Specific Absorption Rate

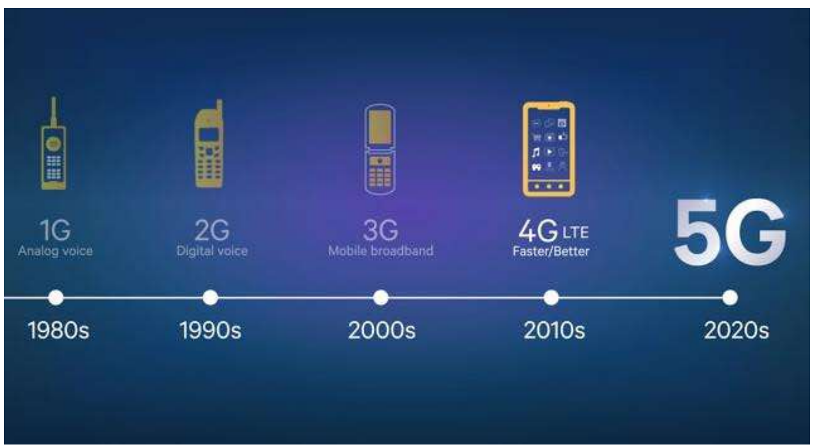


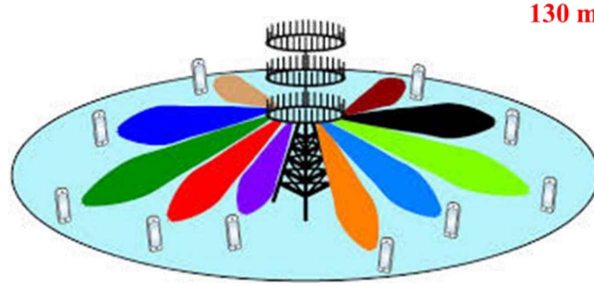
- Specific Absorption Rate
  - Computes W/kg Absorbed in a 1 g Cube
- Solver: MoM/SEP
- Radiated Power: 250 mW
- SAR: 0.2935 W/kg

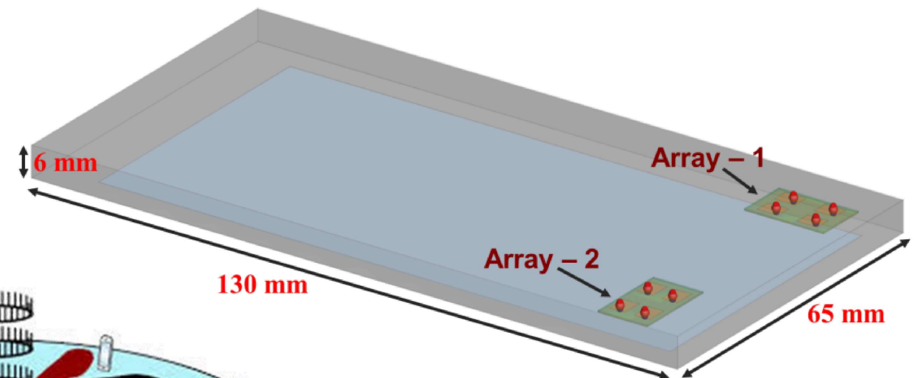
Mesh	Triangles	Mesh Size
Tablet	46,800	2.6 mm
Hand	1,432	6.5 mm

Conclusions

- Challenges in designing antennas for LTE-MIMO systems are discussed
- Design considerations for antennas for smart phones and tablets are presented
- Specific Absorption Rates (SAR) are presented
- Channel Capacity considerations are presented







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